Vol 7 No 2 (2025) *e*-ISSN: 2682-8383

Journal of Engineering Technology and Applied Physics

Effect of Entrance Insulated Inner Absorber on EGATC Thermal Performance – Experimental Approach

Nabila Sulaiman[1, *], Sany Izan Ihsan[1], Zafri Azran Abdul Majid[2] and Syed Noh Syed Abu Bakar[1]
[1]*Department of Mechanical Engineering, Kulliyyah of Engineering, International Islamic University Malaysia (IIUM), Gombak, 53100 Kuala Lumpur, Malaysia.*
[2]*Department of Audiology and Speech-Language Pathology, Kulliyyah of Allied Health Science, International Islamic University Malaysia (IIUM), 25200 Kuantan, Pahang, Malaysia.*
**Corresponding author*: nabilaiium@gmail.com, *ORCiD*: 0000-0002-1982-7038
https://doi.org/10.33093/jetap.2025.7.2.16
Manuscript Received: 28 May 2025, Accepted: 23 July 2025, Published: 15 September 2025

***Abstract*—This study presented the experimental results of using insulated inner absorbers to enhance the thermal performance of the Evacuated Glass Thermal-Absorber Tube Collector (EGATC). The inner absorber of EGATC was insulated with exterior thermal insulation paint. The length of the insulation varied at 20 cm, 30 cm, 40 cm, and 50 cm from the tip of the inner absorber. The thermal performance of the EGATC improved when the insulated inner absorber was utilized compared to instances without insulation. The optimal insulation length for enhancing EGATC's thermal performance was found to be 35 cm from the projection. A follow-up experiment used the 35 cm insulation length to observe its thermal performance patterns. The 30 cm and 35 cm insulation lengths exhibited similar outlet temperatures during charging, confirming that 35 cm was the optimal length for insulating the inner absorber.**

Keywords—Evacuated tube solar collector, Solar thermal, Thermal performance, Aerogel, Insulation paint.

I. INTRODUCTION

Solar thermal energy has garnered significant attention as a viable renewable energy source [1], with solar thermal consumption increasing by 1.2% globally in 2019 [2]. One application of solar thermal technology is the Evacuated Tube Solar Air Collector (ETSAC), which has proven efficient for air heating in cold temperatures [3]. ETSAC transfers the heated air at different temperatures without pressure issues and is designed to prevent damage to the system during heating [4].

Evacuated tubes exhibit lower thermal efficiency due to the limited heat-carrying capacity of air and the lower convective heat transfer coefficient between the air and the absorber surface [5]. Evacuated tube solar collectors have higher heat extraction efficiency at temperatures above 80 °C compared to flat plate collectors [6].

One of ETSACs applications is the Evacuated Glass-Thermal Absorber Collector (EGATC). According to Zakaria *et al.* [7], EGATC outperformed Heat-Pipe ETCs because its double flow design and the superior heat gain of stainless steel as a thermal absorber enhanced its thermal efficiency. The integrated design between the absorber and evacuated glass eliminates both conduction and convection losses between the absorbing surface and outside ambient temperature. In EGATC, forced convection of air moved from the inlet to the outlet. It will go through the inner absorber towards the end and enter the outer absorber to the outlet. The heat is transferred from radiation from halogen lamps to the outer of the glass evacuated tube to the coating and to air trapped between the evacuated tube to the outer absorber and the inner absorber by convection and conduction.

The EGATC consists of stainless steel inner and outer absorbers designed to capture heat from the evacuated tube. The evacuated tube comprises an outer glass layer and an inner absorber. The outer glass layer captures heat from solar radiation and ambient convection, while the inner absorber acquires heat from the outer absorber through conduction and convection. The absorber assembly, including both inner and outer absorbers, receives air that the inner absorber has heated. This heated air moves by convection through the space between the outer and inner absorbers toward the outlet. The absorber collects heat and functions as a thermal storage unit.

Published by MMU PRESS. URL: https://journals.mmupress.com/index.php/jetap/index

In this configuration, the vacuum between the inner and outer glass layers significantly reduces heat loss through conduction and convection, enhancing the collector's efficiency. The inner absorber typically features a selective coating to maximize solar heat absorption while minimizing thermal emission. The heated air can be utilized for various applications, such as space heating, crop drying, or industrial processes requiring thermal energy.

Experimental results indicate that the highest temperature within the EGATC occurs at its central region. During operation, heated air flows from the inner absorber to the outer absorber. However, heat loss through the outer absorber can transfer back toward the entrance region of the inner absorber, causing unintended reheating. This backward heat flow reduces the temperature gradient along the flow path, leading to a lower-than-expected outlet temperature. The application of thermal insulation at the entrance of the inner absorber minimizes this heat loss due to the low thermal conductivity of the insulating material.

II. LITERATURE REVIEW

Numerous studies have been conducted on the design and configuration of ETSACs in order to investigate their thermal performance. A study by Veera Kumar *et al.* [8] has focused on the thermal performance of ETSAC when inserting baffles. The installation of baffles positively impacts the thermal performance of ETSAC. In their study [9], Z. Wang *et al.* showed that an integrated solar air heater with evacuated tubes connected by flat micro-heat pipe arrays can get 1268.8 W of heat and release 98.5% of that heat. Singh and Vardhan [10] assessed the impact of helical inserts on the thermal performance of ETSAC. Dutta *et al.* [11] compared the drying rates of pretreated turmeric in evacuated tubes with and without Phase Change Materials (PCMs), highlighting that tubes without PCMs dried faster, while those with PCMs retained the highest curcumin content. Kumar *et al.* [12] enhanced the thermal performance of an ETSAC by incorporating twisted tape inserts. Abrofarakh and Moghadam [13] used a CFD approach to study the thermal performance of ETSAC with baffles and metal foam. They discovered that the use of metal foam significantly boosts thermal performance, with an average improvement of around 300%. Kushwah *et al.* [14] analyzed the performance of an assisted solar dryer with evacuated tubes, noting a 30% reduction in drying time compared to traditional open drying methods. Yadav *et al.* [15] created a mathematical model for the thin-layer drying of bitter gourd in an ETSAC without a heat pipe. They found that the maximum drying rate reached 15.15 g of moisture per gram of dry matter per hour under high solar radiation of 735 W/m².

Furthermore, other than ETSAC, Solar Air Heater (SAH) also has its own design modification in order to enhance its thermal performance. Madhulatha *et al.* [16] optimized its design by arranging the tubes and installed PCMs in their solar air heater. While Abo-Elfadl *et al.* [17] constructed conductive aluminum tubes adjacent to each other and installed them in the same direction as the air flowing inside the Solar Air Heater (SAH). Ahn and Kim [18] studied the thermal performance of a T-shape obstacle in solar SAH. Saxena *et al.* [19] studied the thermal performance of helical tube carrying phase change material for SAH. Abo-elfadl *et al.* [20] investigated the solar air heater of V-shaped tranverse finned with absorber plate of lateral gaps and central holes at single-pass and double-pass airflow conditions. Moreover, Kalash *et al.* [21] constructed three double pass solar air heaters using ten tubes of aluminum. They used aluminum glass wool to insulate the sides and the bottom base and the stored energy increased during the day and decreased during the night. Madhu *et al.* [22] investigated the effect of coating the absorber plate with higher thermal conductive black paint under forced circulation method and studied under the climatic conditions of Chennai.

Aerogel demonstrated excellent thermal insulation properties [23]. With its low thermal conductivity around 1-19 mW/(m.K) [24], recent studies have shown that aerogel is being used as insulator for buildings [25–29] and other applications [30–32]. Gao *et al.* [33] proposed a structure- optimized evacuated flat plate solar collector with a transparent aerogel layer and back shield plate and enhance at 60.47% which is 20.68% better than prototype. From the best knowledge of the author, no study has been conducted regarding insulation for the thermal performance of ETSACs. Furthermore, insulation of the inner absorber in EGATC was proposed to observe its thermal performance. Insulation minimized heat transfer by reducing the heat surface area of EGATC's inner absorber. It could potentially enhance thermal performance by increasing the outlet temperature and heat gain from solar radiation. The study's objective was to investigate the effect of insulation of the inner absorber on EGATC thermal performance.

III. METHODS AND MATERIAL

A. Experimental Setup

The illustration depicting an EGATC is presented in Fig. 1. Comprising an evacuated tube, a stainless-steel inner absorber, and an outer absorber, the EGATC was constructed using a double-layer evacuated glass tube that terminates in a ventilated chamber. The inner absorber was positioned within the outer absorber of the EGATC to establish a double pass flow design configuration [34]. The space between the two glass tubes was evacuated to generate a vacuum, which served as an insulating medium. The transparency of the outer tube enabled the passage of light rays with minimal reflection.

Additionally, the outer surface of the inner tube was treated with a specialized selective coating of aluminum nitride (Al-N/Al) to capture solar radiation and transform it into thermal energy. This selective absorption coating exhibited a high absorptivity and low emissivity. Table I shows the specification of EGATC.

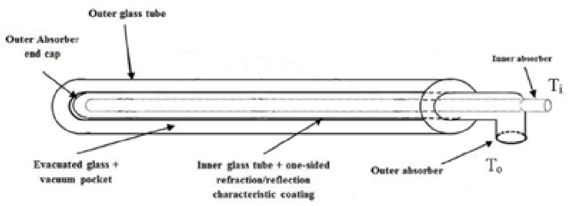

Fig. 1. Schematic diagram of EGATC.

Table I. Specification for EGATC.

Item	Material	Specification
Name of manufacturer		MISOLIE Technology
Vacuum in between outer glass & absorber tube		5 × 10^{-2} Pa
Inner absorber	Stainless steel 304 (Thermal conductivity, k = 16.2 Wm/K at 100 °C)	Inner diameter: 10 mm Outer diameter: 12 mm Length: 620 mm
Outer absorber	Stainless steel 304 (Thermal conductivity, k = 16.2 Wm/K at 100 °C)	Inner diameter: 36 mm Outer diameter: 38 mm Length: 550 mm

The experimental setup with a data logger and fan is shown in Fig. 2. The solar simulator comprised nine halogen lamps to simulate solar radiation, aluminium stands, 3 regulators, a fan, ventilated chamber, a data logger, and EGATC. As solar simulator was switched on, and the temperature readings of charging were recorded for 30 minutes. When the time was up, the halogen lamps were switched off, and the discharging temperature was recorded for 30 minutes. Temperature readings for both charging and discharging conditions were recorded using the data logger.

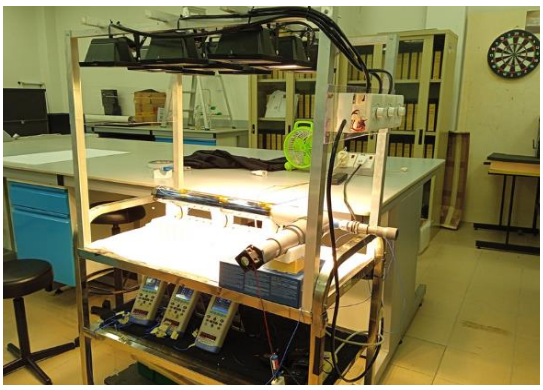

Fig. 2. Experimental set-up of EGATC.

The solar simulator was exposed to radiation of 700 W/m^2. To measure the temperature at the thermal absorber wall and the solar radiation flux, Applent Technologies, Multi-Channel Temperature Meter (8-CH) (AT4208) and Apogee Instruments, Silicon-Cell: Self Powered Pyranometer (SP-110- SS) were utilized. For calibration purposes, the real-time solar radiation flux was measured using Tes Electrical Electronic Corporation, Datalogging Solar Power Meter (TES-1333R). The readings taken by both the Pyranometer and datalogger were calibrated for their validity and reliability before experimenting. The wind speed was measured by TESTO, Digital Display Hot-Wire Anemometer (405-V1).

The room, inlet, and outlet temperature readings from the data logger, radiation from the solar simulator, and the air velocity of the fan were recorded. The EGATC position was aligned with the marking lines. The timer was ready for 30 minutes of charging and another 30 minutes of discharging.

Experiments were conducted by insulating the inner absorber with exterior thermal insulation paint in white colour from Bina Ultrashield Sdn. Bhd [35]. The paint is mixed with aerogel powder, Aerowder with its thermal conductivity of 0.018-0.020 W/m.K [36]. The objective was to investigate the effect of an insulated inner absorber on the thermal performance of the EGATC. The length of insulation varied at 12 cm, 20 cm, 30 cm, 40 cm and 50 cm from the tip of the inlet inner absorber. Figure 3 and Fig. 4 showed the insulation inner absorber and control ones.

Table II shows the parameters for experiments, and Fig. 3 shows the actual model of EGATC. The experiments were conducted with the same parameters as Zakaria *et al.* [7].

Table II. Parameters of the experiments.

Item	Parameters
Initial condition	• Ambient temperature (system) = 28.5 – 30 °C • Ambient temperature (simulator) = 28 °C • Inlet temperature, Ti = 28.6 – 28.8 °C • Outlet temperature, To = 28.6 °C • Air velocity = 0.9 m/s • Solar radiation = 700 W/m^2
Length of insulation	• L_o = 12 cm • L_1 = 20 cm • L_2 = 30 cm • L_3 = 35 cm • L_4 = 40 cm • L_5 = 50 cm
Insulation paint	Exterior thermal insulation paint (Thermal conductivity, k = 0.0017 W.m/K)

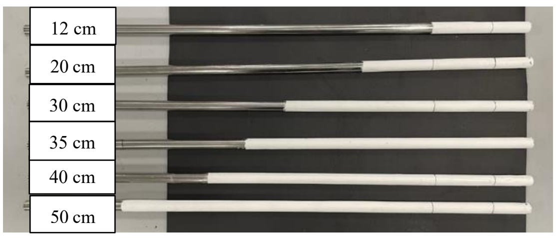

Fig. 3. Insulated inner absorber.

Fig. 4. Control inner absorber.

B. Performance and Efficiency Evaluation of the System

The system in this study was considered a closed system for any velocity and elevation change. Hence, the heat transfer rate of the collector,

$$\dot{Q}_{Collector} = \rho A v C_{p(air)}(T_o - T_i) \quad (1)$$

, where
ρ: air density (kg/m^3)
A: area of inlet duct (m^2)
v: air velocity at inlet duct (m/s)
$C_{p(air)}$: specific heat capacity of air (kJ/kg.K)
T_o: air outlet temperature (K)
T_i: air inlet temperature (K)

Equation (1) was used to convert energy from solar radiation into heat to increase the outlet temperature of the collector by referring to the inlet temperature. Meanwhile, Eq. (2) was used to calculate energy from solar radiation that was converted into energy storage in the thermal absorber by referring to instantaneous energy accumulation for each second. The heat transfer rate of the thermal absorber storage is expressed as,

$$\dot{Q}_{store} = m_{ab} C_{p(ab)}(T_2 - T_1)/(t_2 - t_1) \quad (2)$$

, where
m_{ab}: mass of absorber (kg)
$C_{p(ab)}$: specific heat capacity for thermal absorber (kJ/kg.K)
T_2: temperature of thermal absorber after heat gain (K)
T_1: temperature of thermal absorber before heat gain (K)
t_2: time after record (s)
t_1: initial time of record (s)

IV. RESULTS AND DISCUSSION

This section investigated the thermal performance of EGATC with an insulated inner absorber. The thermal insulation paint is the combination of aerogel and exterior paint for houses by BINA named BINA Ultrashield [35]. As aerogel has low thermal conductivity, mixing it with BINA Ultrashield emulsion paint, the study of its effectiveness has been conducted by Rahim *et al.* [36]. It shows that the combination of aerogel in the paint has insulated the house better than without it. Thus, the insulation paint has been applied to inner absorber of EGATC to observe its effect on thermal performance.

The experiment results of applying the thermal insulation paint to the inner absorber are shown in Fig. 5. It shows the outlet temperature vs. time during charging and discharging. The outlet temperatures of insulated inner absorbers at lengths of 12 cm, 20 cm, 30 cm, 40 cm and 50 cm were compared with those of control ones.

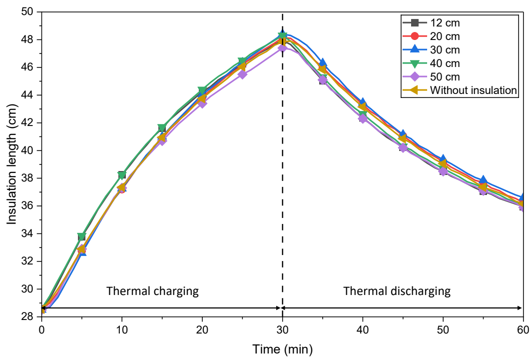

Fig. 5. Comparison of outlet temperature vs time during charging and discharging for different length of insulated inner absorber and without insulation.

Figure 5 shows that the thermal performance of the EGATC varied with different length of insulated inner absorber and without insulation. The insulation length of 12 cm exhibited a higher outlet temperature than the control during charging, but a lower temperature than the control during discharging. An insulation length of 20 cm showed identical outlet temperature with control during charging and discharging. In contrast, a 30 cm of insulation length had a higher outlet temperature compared to control during charging and discharging. However, insulation lengths of 40 cm and 50 cm resulted in lower outlet temperatures than the control during charging and discharging.

The purpose of insulating the inner absorber to a specific length was to reduce heat loss to the surroundings, which would affect the EGATC thermal performance. The lengths of the insulated inner absorber affected the performance of energy converted from solar radiation to heat energy. It could be observed that there were differences in outlet temperatures due to the exposure area of the inner absorber from insulation.

The experimental results demonstrated that the thermal performance of insulated inner absorbers varied with different lengths, affecting the thermal performance of EGATC. An insulated inner absorber length of 30 cm produced the highest outlet temperature compared to other lengths.

Inadequate optimization of the inner absorber's insulation length led to more heat losses in the EGATC because of greater surface area was exposed to convection and radiation. Beyond a certain length, the performance became less significant. Therefore, it was crucial to optimize the insulation length based on the specific to achieve the desired thermal performance.

The EGATC featured a broad surface area contact between the thermal absorber and air, allowing it convert the heat directly. In contrast, Heat Pipe Evacuated Tube Collectors depended on a heat pipe condenser that has a smaller surface area. As a result, the area and duration of heat transfer were the significant factors in developing a higher temperature difference between the inlet and outlet temperatures [37].

Following that, Fig. 6 shows the graph for comparison of maximum outlet temperature for different insulation lengths and without insulation during charging. The graph indicated that an insulation length of 30 cm yielded the optimum maximum temperature. As the insulation length increased from 12 cm to 30 cm, the maximum temperature rose steadily. However, beyond 30 cm, the temperature began to decline and continuing this trend until reaching 50 cm. Thus, it could be predicted that 30 cm was the ideal insulation length for the inner absorber.

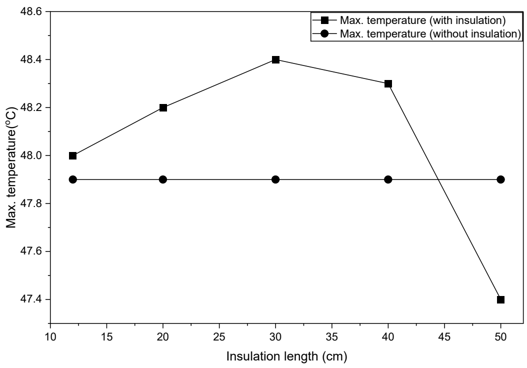

Fig. 6. Comparison of maximum outlet temperature (charging) of insulation lengths and without insulation.

A. Outlet Temperature

From the experiments, the maximum temperature of the evacuated tube was higher in the middle and lowest at the end of the evacuated tube. From these characteristics, it was important to insulate the inner absorber from the starting to the middle of it to reduce the heat loss. The insulation helps prevent the inlet temperature at the inner absorber from being reheated by the heated air moves from the inner absorber to the outlet of the outer absorber.

B. Energy Gain of Air

The influence of aerogel paint insulation length on the heat transfer rate of the EGATC was evaluated during both the charging and discharging phases. As shown in Table III, the highest heat transfer rate during the charging phase was recorded at the shortest insulation length of 12 cm, 0.01139 kW. This suggests that minimal insulation allows for greater exposure of the inner absorber surface to incident thermal radiation therefore enhancing heat absorption. However, as the insulation length increased beyond 20 cm, a gradual decline in charging performance was observed. The heat transfer rate dropped particularly after 35 cm, from 0.01103 kW and further decreased to 0.01080 kW at 50 cm. This decline can be attributed to the increased thermal resistance introduced by the extended insulation coverage which may have restricted the surface area available for direct heat absorption.

Table III. Effect of insulation length on heat transfer rate.

Insulation length (cm)	Heat transfer rate of air (kW)	
	Charging at 30 mins	Discharging at 60 mins
12	0.01139	0.00393
20	0.01064	0.00397
30	0.01126	0.00390
35	0.01126	0.00403
40	0.01103	0.00416
50	0.01080	0.00429

In contrast, the discharging phase exhibited a steady increase in heat transfer rate with longer insulation lengths from 0.00393 kW at 12 cm to 0.00429 kW at 50 cm. This trend indicates that extended insulation coverage plays a significant role in minimizing heat losses to the environment thus enhancing the thermal retention capability of the system. Notably, at 30 cm and 35 cm, the system maintained a relatively high charging heat transfer rate 0.01126 kW while beginning to show improved discharging performance, suggesting a transitional balance between heat gain and retention.

Overall, the results demonstrate a trade-off between rapid thermal absorption and long-term thermal retention. While shorter insulation lengths may improve charging efficiency, longer insulation enhances discharging stability. The optimum performance appears to occur in the range of 30 to 35 cm where both charging and discharging rates are reasonably maintained. These findings emphasize the importance of optimizing insulation length to achieve a balanced thermal response and may inform future designs incorporating variable or selective insulation strategies to improve the efficiency of EGATC.

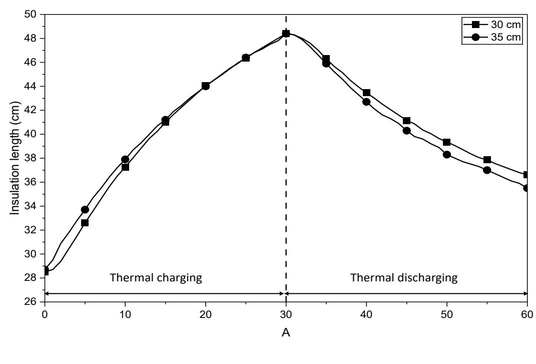

Fig. 7. Comparison of outlet temperature for insulation length of 30 cm and 35 cm.

In comparing the insulation lengths of 30 cm and 35 cm, both demonstrated identical outlet temperatures during the charging process. Figure 7 shows the comparison outlet temperature for insulation length of 30 cm and 35 cm. The difference of outlet temperatures for 30 cm and 35 cm is in the range of 0.05 to 1.5 °C during charging and 0.1 to 1.05 °C during discharging. There is not so much difference between these two insulation lengths. Thus, the thermal performance for EGATC is identical.

V. CONCLUSION & RECOMMENDATION

A. Conclusion

Experimental studies have been conducted to evaluate the performance of the EGATC with and without the inner absorber insulation. The following conclusions have been drawn:

1. Insulating the inner absorber improved the thermal performance of the EGATC.
2. The insulated inner absorber of EGATC performs better than the non-insulated inner absorber of EGATC at the insulation lengths of 12 cm, 20 cm, 30 cm, 35 cm and 40 cm.
3. The optimal insulation length for this design was 30 cm, maximizing EGATC's thermal performance.
4. Both 30 cm and 35 cm insulation lengths showed identical results of EGATC's thermal performance.
5. The energy gain from the insulated inner absorber was higher than the uninsulated version.
6. Thermal insulation paint of mixed aerogel and BINA Ultrashield has an effect on EGATC thermal performance.

B. Recommendation

1. Modeling the experiments with simulation to validate EGATC's thermal performance.
2. Varying the thermal insulation paint with other brands or mixtures to be painted on the inner absorber of EGATC.
3. Paint EGATC's outside outer absorber with higher thermal conductivity paint to increase its heat absorption.
4. Lower the air velocity at the inlet to increase its reside time in the EGATC's inner absorber.

ACKNOWLEDGEMENT

The authors wish to express their gratitude to Kulliyyah of Engineering (KOE) and Kulliyyah of Allied Health Sciences (KAHS), International Islamic University Malaysia (IIUM) together with Aerodynamics, Heat transfer and Propulsion Group, Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia (UPM) for exterior thermal insulation paint.

FUNDING

This study was not supported by any grants from funding bodies in the public, private, or not-for-profit sectors.

REFERENCES

[1] K. R. Kumar, N. V. V. K. Chaitanya and N. S. Kumar, "Solar Thermal Energy Technologies and Its Applications for Process Heating and Power Generation – A Review," *J. Clean. Prod.*, vol. 282, pp. 125296, 2021.

[2] "Tracking SDG7: The Energy Progress Report 2022," IEA, Paris, 2022. [Available online] https://www.iea.org/reports/tracking-sdg7-the-energy-progress-report-2022.

[3] A. Yadav and V. K. Bajpai, "An Experimental Study on Evacuated Tube Solar Collector for Heating of Air in India," *World Acad. Sci. Eng. Technol.*, vol. 79, no. 7, pp. 81–86, 2011.

[4] N. Sulaiman, S. I. Ihsan, S. N. S. Abu Bakar, Z. A. Abdul Majid and Z. A. Zakaria, "Evacuated Tube Solar Air Collectors : A Review of Design Configurations , Simulation Works , And Applications," *Prog. Ener. Environ.*, vol. 25, pp. 10-32, 2023.

[5] A. Elbrashy, F. Aboutaleb, M. El-Fakharany and F. A. Essa, "Experimental Study of Solar Air Heater Performance with Evacuated Tubes Connected in Series and Involving Nano-Copper Oxide/Paraffin Wax as Thermal Storage Enhancer," *Environ. Sci. Pollut. Res.*, vol. 30, pp. 4603–4616, 2022.

[6] R. Chaudhary and A. Yadav, "Experimental Investigation of Solar Cooking System Based on Evacuated Tube Solar Collector for The Preparation of Concentrated Sugarcane Juice Used in Jaggery Making," *Environ. Dev. Sustain.*, vol. 23, pp. 647–663, 2021.

[7] Z. A. Zakaria *et al.*, "Investigation on The Thermal Performance of Evacuated Glass-Thermal Absorber Tube Collector (EGATC) for Air Heating Application," vol. 2, no. 2, pp. 48–64, 2021.

[8] A. V. Kumar, T. V. Arjunan, D. Seenivasan, R. Venkatramanan and S. Vijayan, "Thermal Performance of An Evacuated Tube Solar Collector with Inserted Baffles for Air Heating Applications," *Sol. Ener.*, vol. 215, no. September 2020, pp. 131–143, 2021.

[9] Z. Wang, Y. Diao, Y. Zhao, C. Chen, L. Liang and T. Wang, "Thermal Performance of Integrated Collector Storage Solar Air Heater with Evacuated Tube and Lap Joint-Type Flat Micro-Heat Pipe Arrays," *Appl. Ener.*, vol. 261, no. December 2019, pp. 114466, 2020.

[10] I. Singh and S. Vardhan, "Experimental Investigation of An Evacuated Tube Collector Solar Air Heater with Helical Inserts," *Renew. Ener.*, vol. 163, pp. 1963–1972, 2021.

[11] C. Dutta, D. K. Yadav, V. K. Arora and S. Malakar, "Drying Characteristics and Quality Analysis of Pre-Treated Turmeric (Curcuma Longa) using Evacuated Tube Solar Dryer with and without Thermal Energy Storage," *Sol. Ener.*, vol. 251, pp. 392–403, 2023.

[12] A. V. Kumar, T. V Arjunan, D. Seenivasan, R. Venkatramanan, S. Vijayan and M. Matheswaran, "Influence of Twisted Tape Inserts on Energy and Exergy Performance of An Evacuated Tube-Based Solar Air Collector," *Sol. Ener.*, vol. 225, no. April, pp. 892–904, 2021.

[13] M. Abrofarakh and H. Moghadam, "Investigation of Thermal Performance and Entropy Generation Rate of Evacuated Tube Collector Solar Air Heater with Inserted Baffles and Metal Foam : A CFD Approach," *Renew. Ener.*, vol. 223, no. October 2023, pp. 120022, 2024.

[14] A. Kushwah, A. Kumar, A. Pal and M. Kumar Gaur, "Experimental Analysis and Thermal Performance of Evacuated Tube Solar Collector Assisted Solar Dryer," *Mater. Today Proc.*, vol. 47, pp. 5846–5851, 2021.

[15] D. K. Yadav, P. Dhurve and V. K. Arora, "Mathematical Modeling and Drying Characteristics of Thin Layer Drying of Bitter Gourd in Evacuated Tube Solar Dryer-Without Heat Pipe," *J. Phys. Conf. Ser.*, vol. 2312, no. 1, 2022.

[16] G. Madhulatha, M. M. J. Kumar and P. Sateesh, "Optimization of Tube Arrangement and Phase Change Material for Enhanced Performance of Solar Air Heater - A Numerical Analysis," *J. Ener. Stor.*, vol. 41, no. May, pp. 102876, 2021.

[17] S. Abo-Elfadl, H. Hassan and M. F. El-Dosoky, "Study of The Performance of Double Pass Solar Air Heater of A New Designed Absorber: An Experimental Work," *Sol. Ener.*, vol.

198, no. January, pp. 479–489, 2020.
[18] S. Y. Ahn and K. Y. Kim, "Thermal Performance of T-shaped Obstacles in A Solar Air Heater," 2020. [Available online] https://www.scribd.com/doc/265667918/Air-Heater.
[19] A. Saxena, N. Agarwal and E. Cuce, "Thermal Performance Evaluation of A Solar Air Heater Integrated with Helical Tubes Carrying Phase Change Material," *J. Ener. Stor.*, vol. 30, no. January, pp. 101406, 2020.
[20] S. Abo-elfadl, M. F. El-dosoky and H. Hassan, "Energy and Exergy Assessment of New Designed Solar Air Heater of V-Shaped Transverse Finned Absorber at Single- and Double-Pass Flow Conditions," *Environ. Sci. Pollut. Res.*, vol. 28, pp. 69074–69092, 2021.
[21] A. R. Kalash, S. S. Shijer and L. J. Habeeb, "Thermal Performance Improvement of Double Pass Solar Air Heater," *Mech. Eng. Res. Dev.*, vol. 43, no. 5, pp. 355-372, 2020.
[22] B. Madhu, A. E. Kabeel, R. Sathyamurthy and S. W. Sharshir, "Investigation on Heat Transfer Enhancement of Conventional and Staggered Fin Solar Air Heater Coated with CNT-Black Paint — An Experimental Approach," *Environ. Sci. Pollut. Res.*, vol. 27, pp. 32251–32269, 2020.
[23] A. V. Fedyukhin *et al.*, "Aerogel Product Applications for High-Temperature Thermal Insulation," *Energies*, vol. 15, no. 20, pp.7792, 2022.
[24] A. Berge and P. Ä. R. Johansson, "Literature Review of High Performance Thermal Insulation," *Rep. in Build. Phys.*, Chalmers University of Technology, 2012.
[25] S. Golder, R. Narayanan, R. Hossain and M. R. Islam, "Experimental and CFD Investigation on The Application for Aerogel Insulation in Buildings," *Energies*, vol. 14, no. 11, pp. 3310, 2021.
[26] D. H. Mutlu and A. Neslihan, "Thermal Insulation Materials in Architecture: A Comparative Test Study with Aerogel and Rock Wool," *Environ. Sci. Pollut. Res.*, vol. 29, pp. 72979–72990, 2022.
[27] A. W. Bashir and B. C. C. Leite, "Performance of Aerogel as A Thermal Insulation Material Towards A Sustainable Design of Residential Buildings for Tropical Climates in Nigeria," *Ener. Built Environ.*, vol. 3, no. 3, pp. 291–315, 2022.
[28] R. Baetens, B. P. Jelle and A. Gustavsen, "Aerogel Insulation for Building Applications: A State-of-The-Art Review," *Ener. Build.*, vol. 43, no. 4, pp. 761–769, 2011.
[29] S. K. Adhikary, D. K. Ashish and Ž. Rudžionis, "Aerogel Based Thermal Insulating Cementitious Composites: A Review," *Ener. Build.*, vol. 245, pp. 111058, 2021.
[30] Y. Tan, W. Chen, Y. Fang, M. Cheng and S. Wang, "Investigation of Novel Expandable Polystyrene/Alumina Aerogel Composite Thermal Insulation Material," *Energy*, vol. 284, pp. 129238, 2023.
[31] Y. H. Wang *et al.*, "Industrial Application of SiO_2 Aerogel Prepared by Supercritical Ethanol (SCE) Drying Technique as Cold and Heat Insulation Materials," *J. Sol-Gel Sci. Technol.*, vol. 106, pp. 341–348, 2022.
[32] Y. Qiu, Y. Zhang, Q. Li, Y. Xu and Z. X. Wen, "A Novel Parabolic Trough Receiver Enhanced by Integrating A Transparent Aerogel and Wing-Like Mirrors," *Appl. Ener.*, vol. 279, pp. 115810, 2020.
[33] D. Gao, L. Wu, Y. Hao and G. Pei, "Ultrahigh-efficiency Solar Energy Harvesting via A Non-Concentrating Evacuated Aerogel Flat-Plate Solar Collector," *Renew. Ener.*, vol. 196, pp. 1455–1468, 2022.
[34] Z. A. Zakaria *et al.*, "Mathematical Model Development of Evacuated Glass-Thermal Absorber Tube Collector (EGATC) for Air Heating Application," vol. 11, no. 1, pp. 73–82, 2023.
[35] B. Ultrashield, "Bina Integrated Industries Sdn Bhd (BIISB)," 2022. [Available online] https://www.binapaint.com.my/product/
[36] A. T. A. Rahim *et al.*, "Effect of Different Aerogel Percentage Coating on Thermal Insulating Performance," vol. 28, no. 1, pp. 155–162, 2024.
[37] E. Vengadesan and R. Senthil, "A Review on Recent Developments in Thermal Performance Enhancement Methods of Flat Plate Solar Air Collector," *Renew. Sustain. Ener. Rev.*, vol. 134, no. November 2019, pp. 110315, 2020.